KEY ASPECTS OF CORONAL HEATING

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A

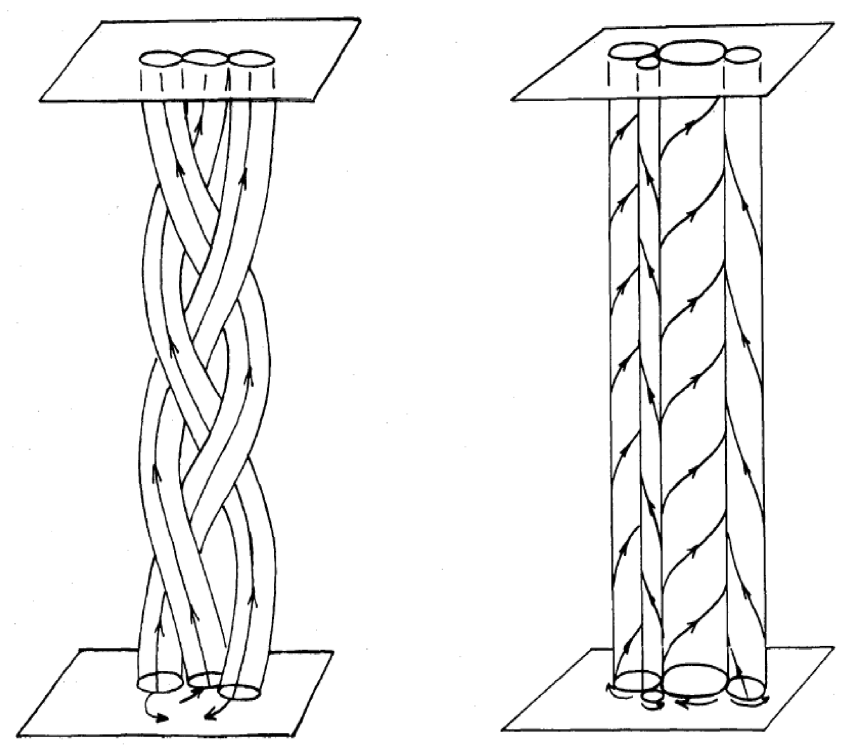
Introduction

We highlight ten key aspects of coronal heating that must be understood before we can consider the problem to be solved:

(1) All coronal heating is impulsive.
(2) The details of coronal heating matter.
(3) The corona is filled with elemental magnetic stands.
(4) The corona is densely populated with current sheets.
(5) The strands must reconnect to prevent an infinite buildup of stress.
(6) Nanoflares repeat with different frequencies.
(7) What is the characteristic magnitude of energy release?
(8) What causes the collective behavior responsible for loops?
(9) What are the onset conditions for energy release?
(10) Chromospheric nanoflares are not a primary source of coronal plasma.

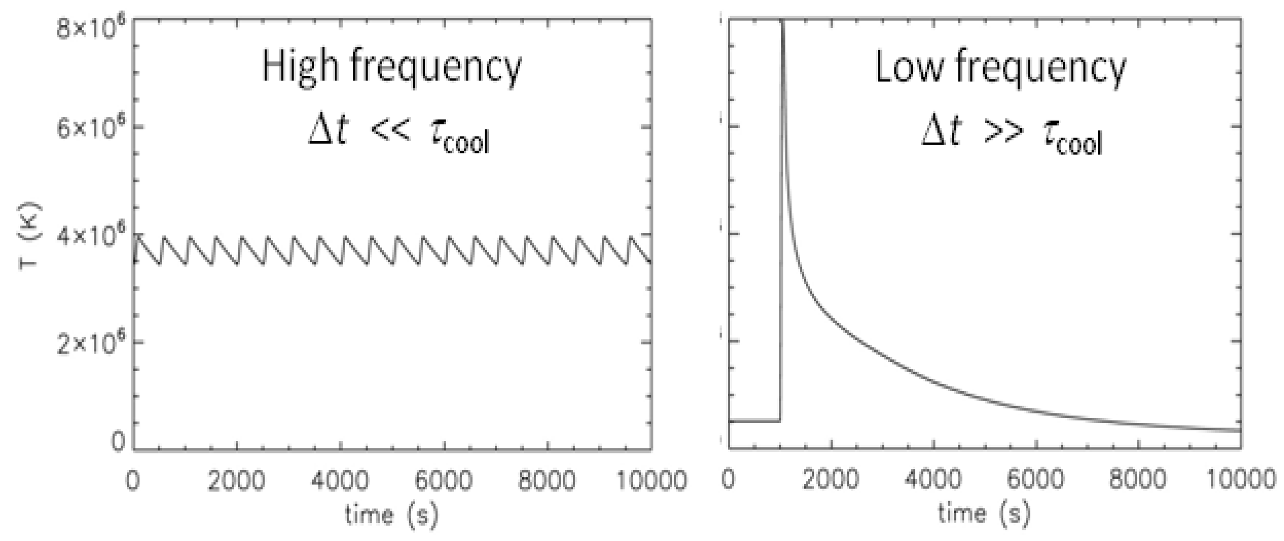
A full discussion of all ten can be found in Klimchuk (2015; arXiv:1410.5660), but we highlight a subset here.

B



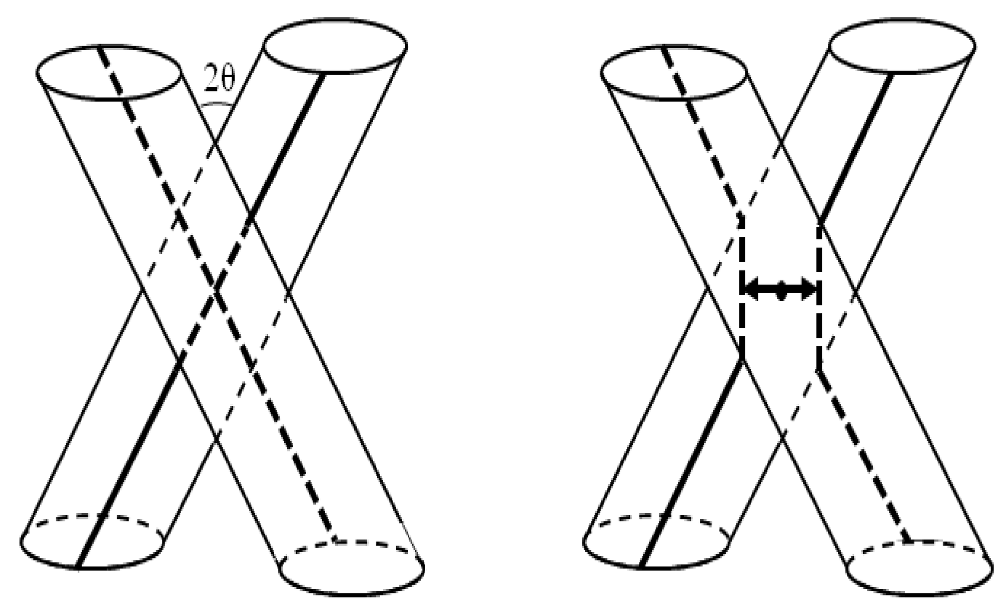
Alfven wave turbulence can cause nanoflares, but we here consider the reconnection of tangled and twisted magnetic strands. (from Parker 1983)

C



Nanoflares repeat along a magnetic strand with high or low frequency relative to the cooling timescale. High-frequency nanoflares are similar to steady heating; temperature fluctuates about a mean value. Low-frequency nanoflares allow full cooling from high to low temperature. Observations reveal that the corona has both types.

D



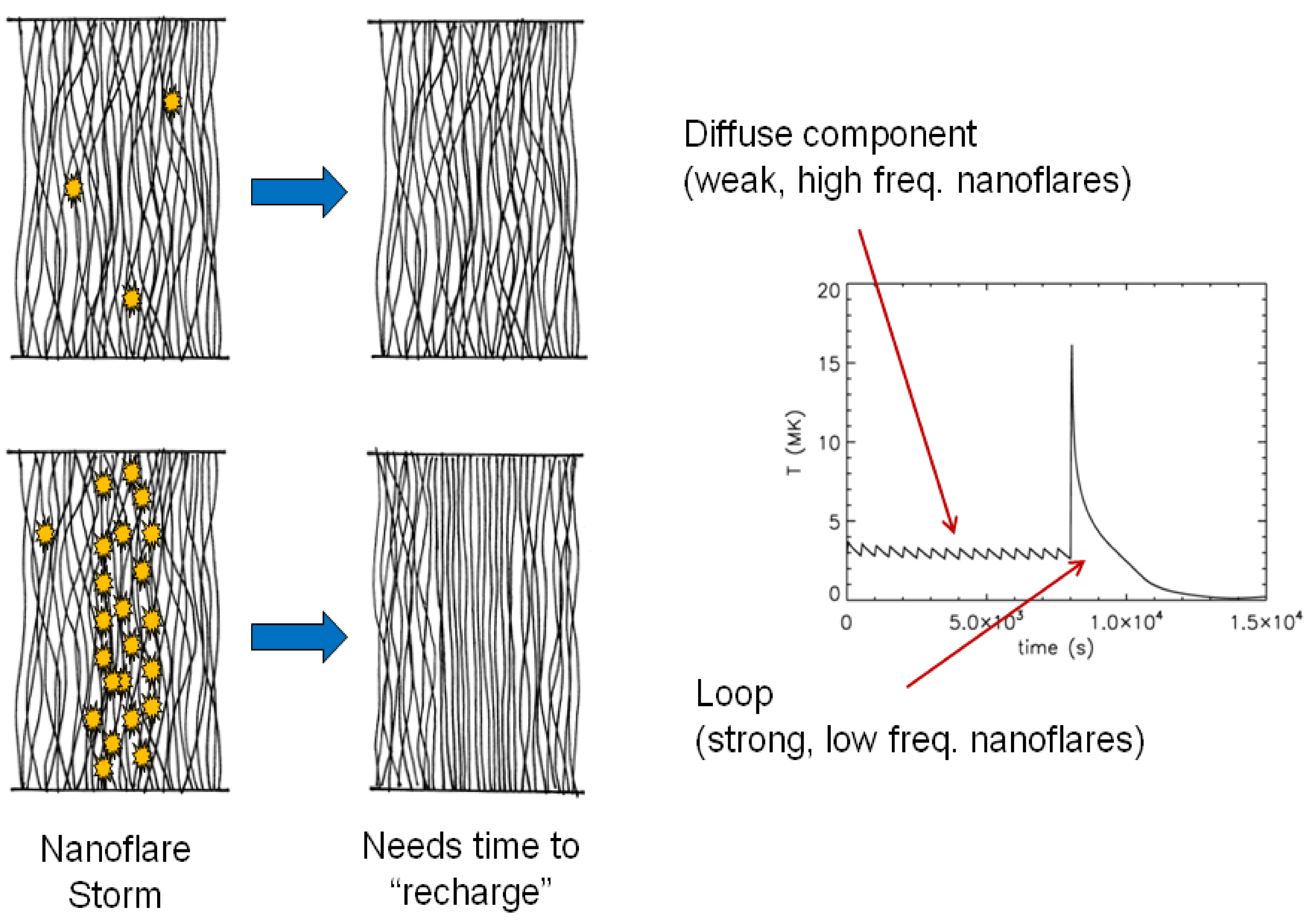
Misaligned strands press against each other with a finite surface of contact. Field lines pull away after reconnecting, but are prevented from going beyond the contact surface by other field lines outside the strands, not shown. Energy release is roughly proportional to the decrease in length and given by (per unit cross sectional area of reconnecting flux):

$$\frac{\Delta E}{A} = \frac{1}{8\pi} r B^2 \left(\frac{\sec\theta - 1}{\sin\theta}\right),$$

where r is the strand radius, B is the field strength, and θ is the misalignment half angle. Observationally based values give $1.0\text{x}10^9$ erg cm^{-2} in active regions. The known energy loss rate of $1.0\text{x}10^7$ erg cm^{-2} s^{-1} implies an average delay between successive events ~100 s. The quiet Sun delay is ~230 s. These are only typical values and correspond to high-frequency heating.

G

Possible unifying picture:
The diffuse corona is heated by high to intermediate frequency reconnection events of a random nature. Magnetic stressing and reconnection are in a statistical steady state. Bright loops occur when spatial and temporal clustering produce intense nanoflares. This can only happen at low frequency due to the longer "recharge" time. What causes this collective behavior? Does one event trigger other events in an avalanche, or are all events activated by a single source (e.g., resistive internal kink instability)?



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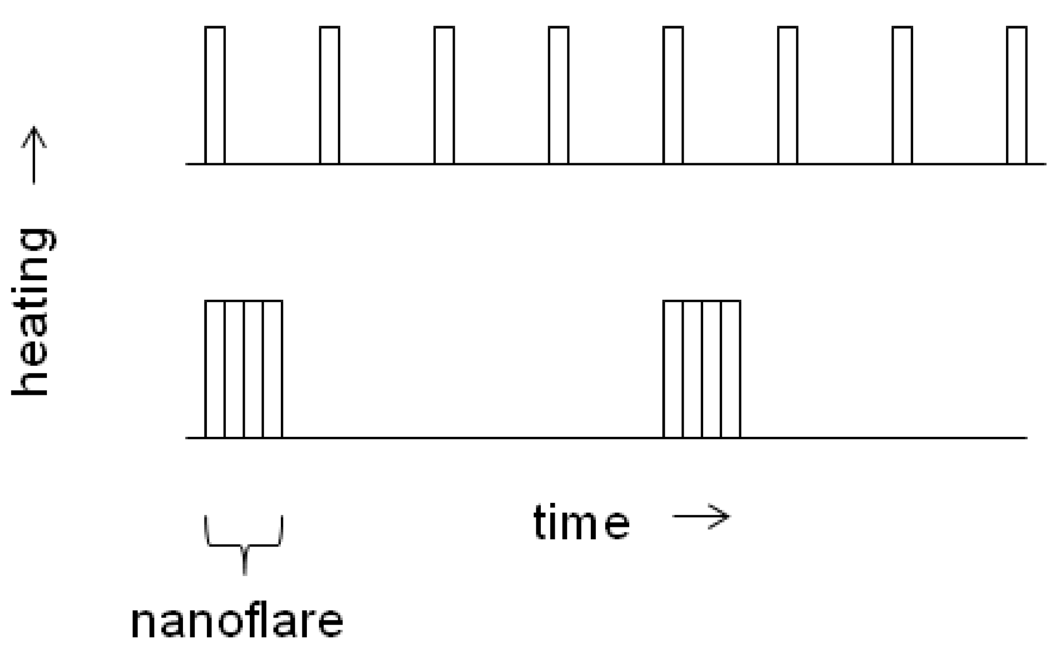
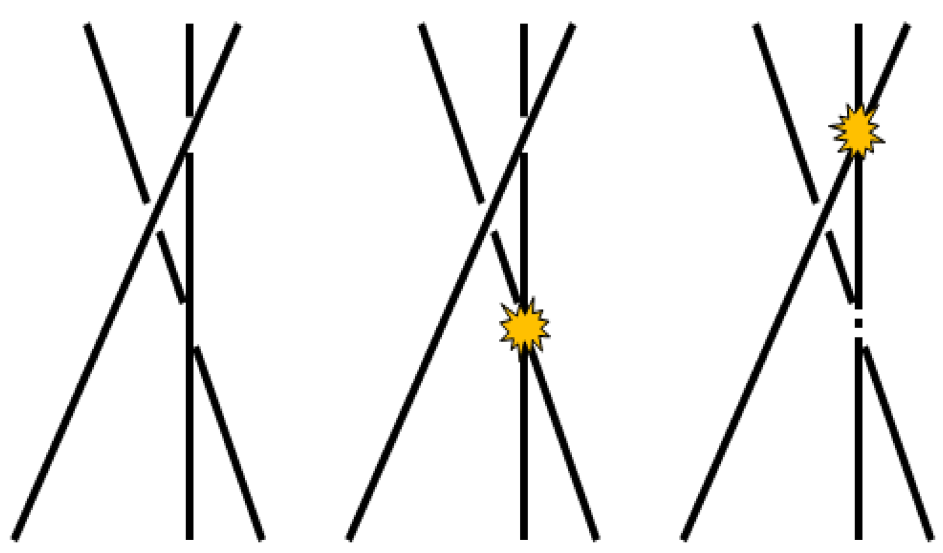


Multiple reconnection events can combine to form a single large nanoflare. Thus, we can have low-energy, high-frequency nanoflares or high-energy, low-frequency nanoflares.

E



A given strand can reconnect with multiple other strands, possibly in rapid succession.

H

We are performing MHD and particle-in-cell (PIC) simulations to rigorously address these ideas. See the Knizhnik et al. poster, for example.